Recent Experiences with Aging in RPC Systems

Workshop on Aging
in Gaseous Detectors
Hamburg, Germany

October 5, 2001

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Talk Outline

- A provocation!
- RPC basics
- Experience in Belle
- Experience in BaBar
- Conventional Aging (LHC)
- Conclusions and Summary

A Provocation: the Promise

Mid 1990s: RPCs are thought to be a robust, economical, and proven technology ideally suited to large-area detection systems. Both Belle and BaBar adopt them for their muon systems.

. . . A Provocation: The Reality

September 1998: Belle is forced to switch off its RPC system in the face of a rapid deterioration in detection efficiency. The system is quickly dying.

October 2000: A BaBar review committee writes: "*The IFR was identified by BaBar as an area of major concern. There is substantial degradation of the efficiency of the RPCs. If this continues, it is likely that muon identification will be fatally impaired by the end of 2002 . . .* "

Notes

- In this talk I will attempt to describe what went wrong.

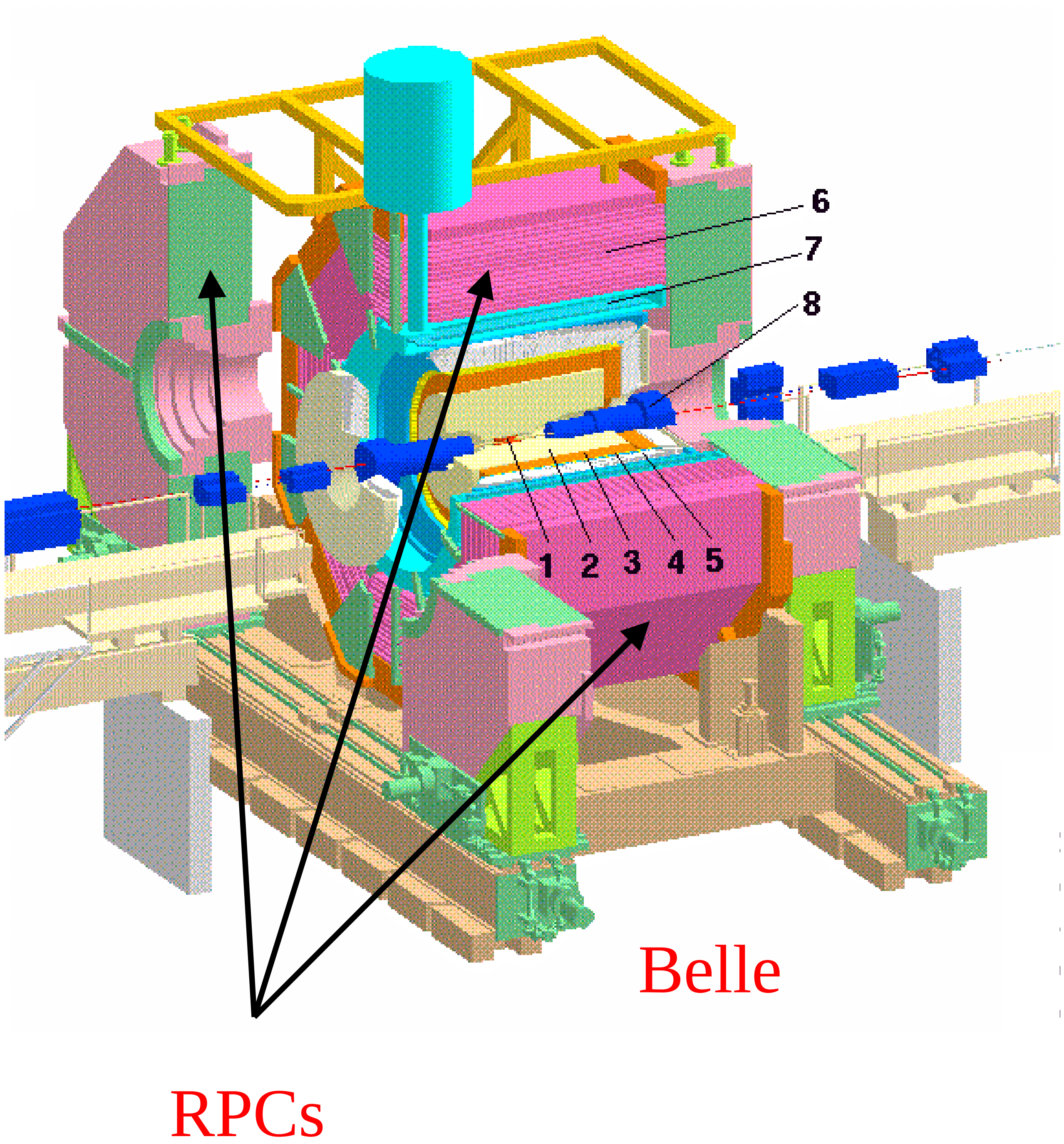
- I will spend more time on Belle since that story may not be as well known and since there will be a separate presentation by BaBar in the next talk.

- I will comment briefly on the prospects for LHC, but once again there will be separate talks from ATLAS and CMS.

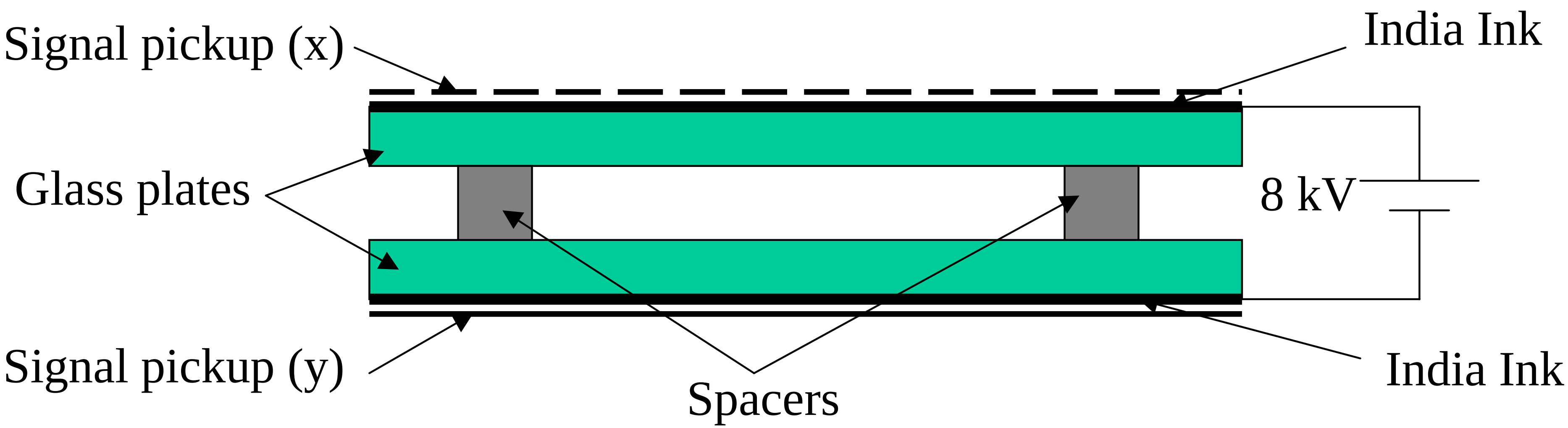
Both Belle and BaBar have instrumented their flux returns.

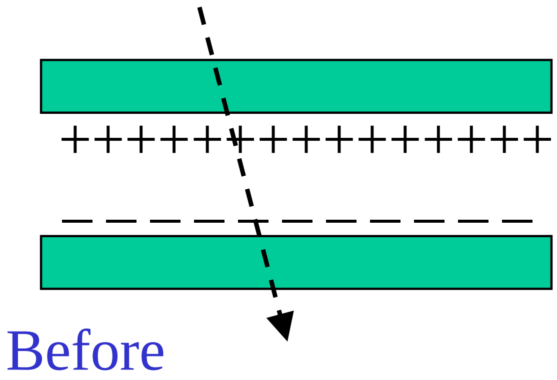
Requirements:

- Low rates
- Modest pos. res.
- Good efficiency
- Large area:
  - low cost
  - easy assembly
  - simple electronics

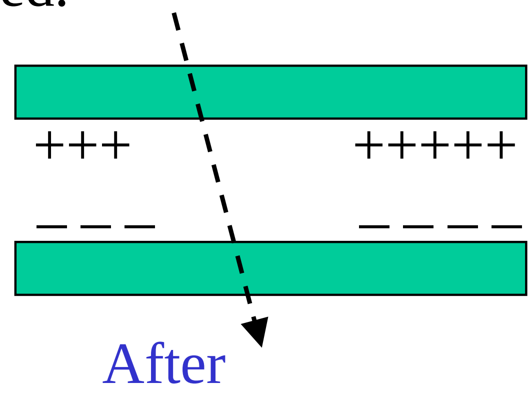


RPC Principles of Operation



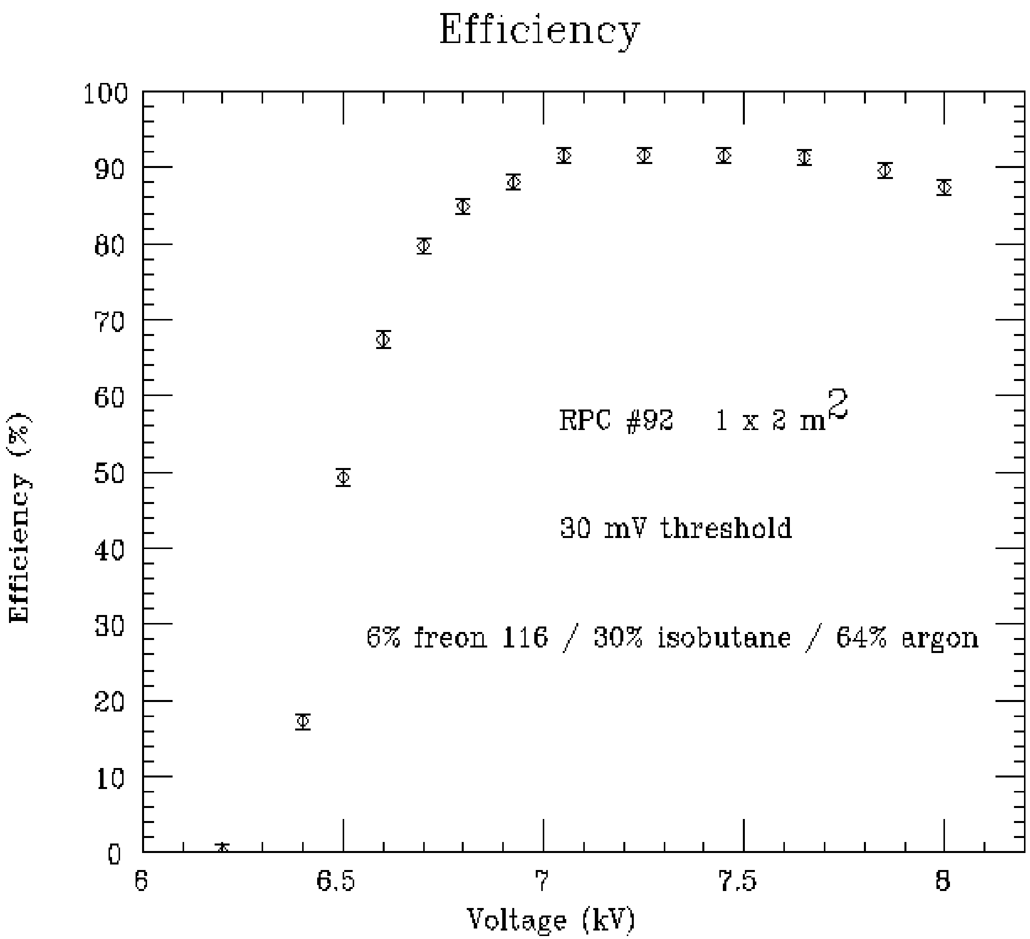


A passing charged particle induces an avalanche, which develops into a spark. The discharge is quenched when all of the locally $(r \approx 0.1\,\mathrm{cm}^2)$ available charge is consumed.



The discharged area recharges slowly through the high-resistivity glass plates.

Plateau Curve

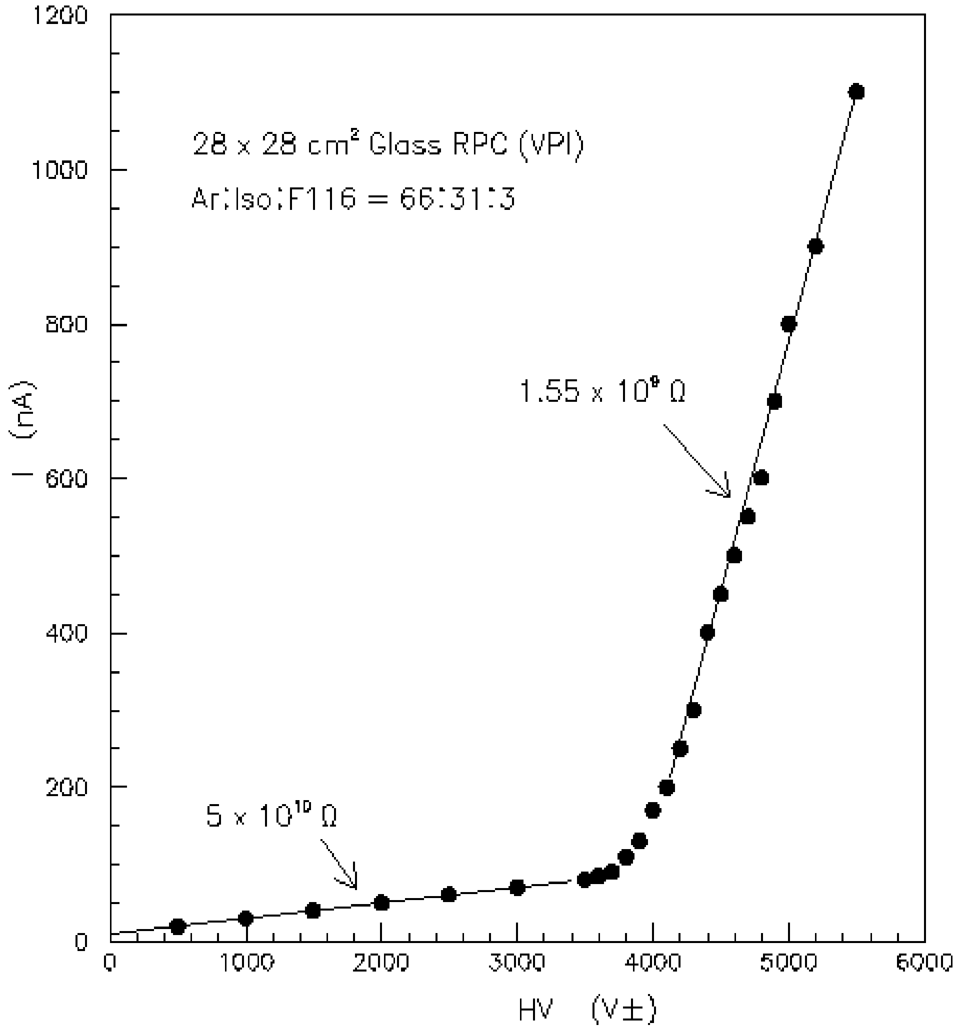


2 mm gap RPCs plateau at a fairly high voltage.

By using both positive and negative supplies one can avoid the complications of a single-ended 7.5 kV HVPS.

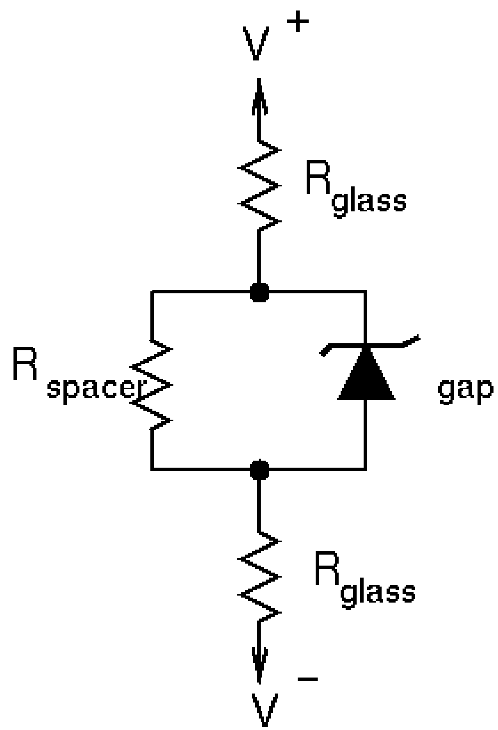
Note the slight falloff in efficiency well above the plateau. This effect is real and typical in glass RPCs.

Principles of Operation: I vs V Curve



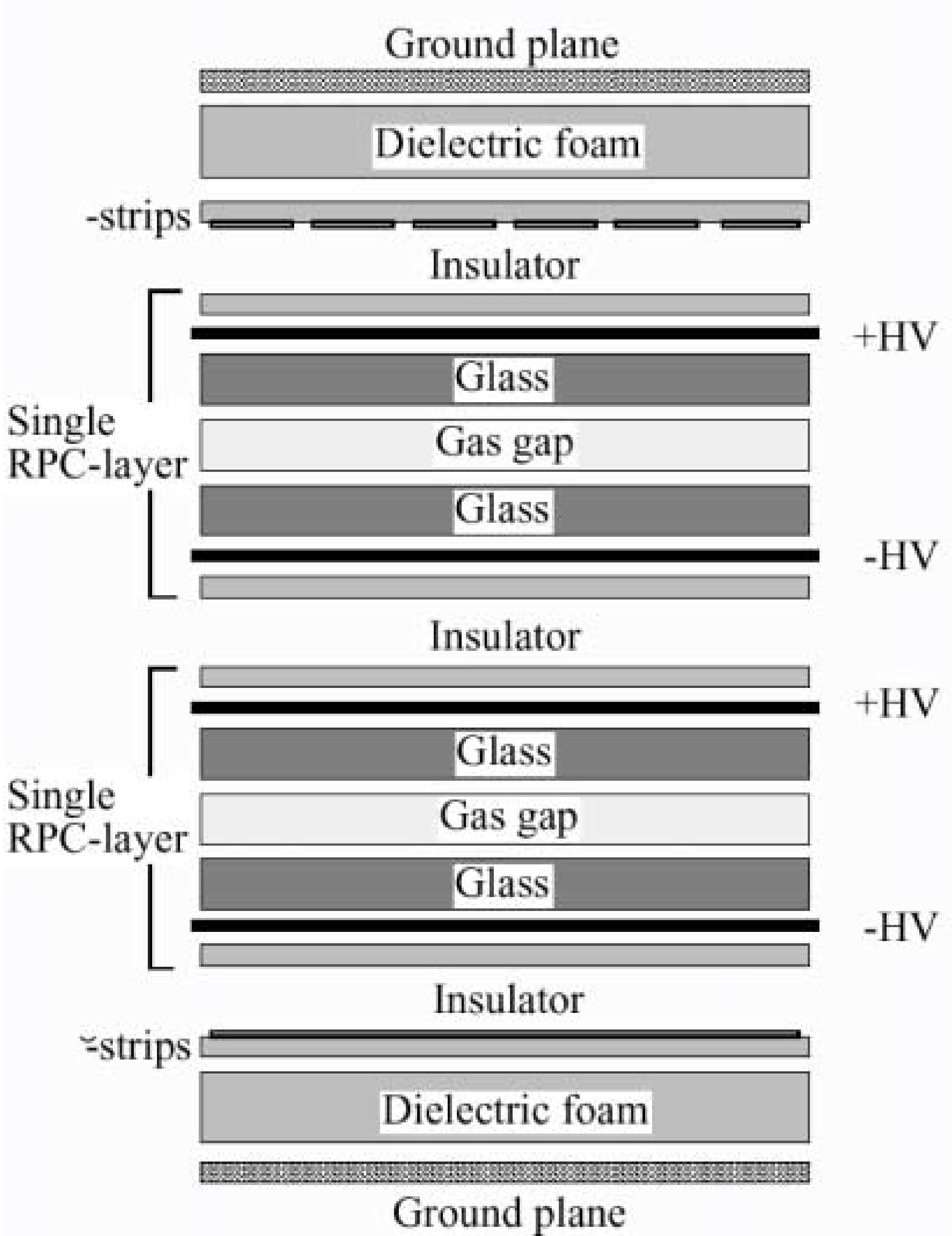
Glass RPCs have a distinctive and readily understandable current versus voltage relationship.

- Low voltage
  - $R_{gap} \approx \propto$
  - $\dfrac{dV}{dI} = R_{spacer}$
- High voltage
  - $R_{gap} \approx 0$
  - $\dfrac{dV}{dI} = R_{glass}$

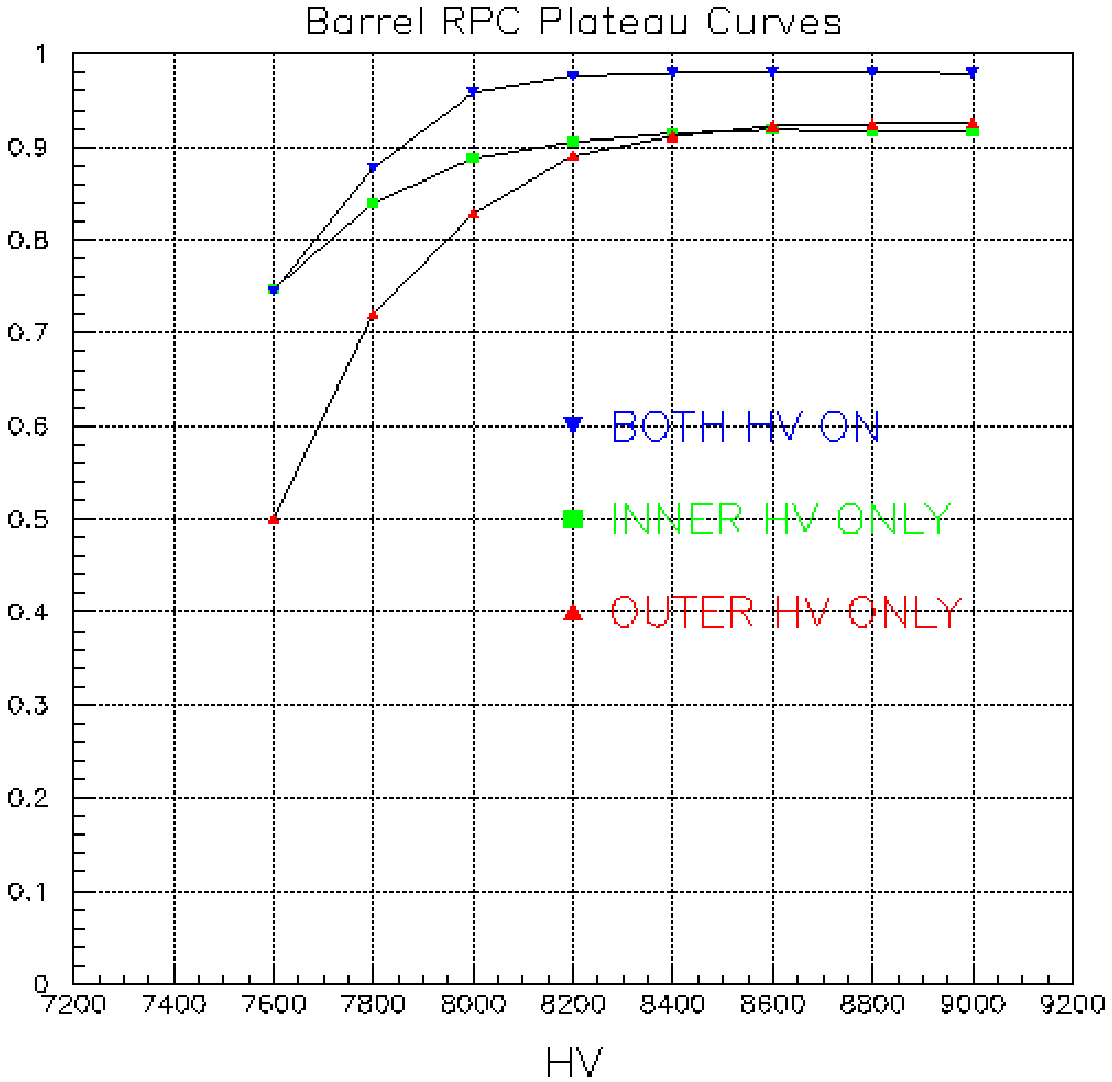


Redundant Design

One very fortunate aspect of the Belle design is that each set of pickup strips (*x* & *y*) "sees" two gas gaps. This has really helped to save our bacon.



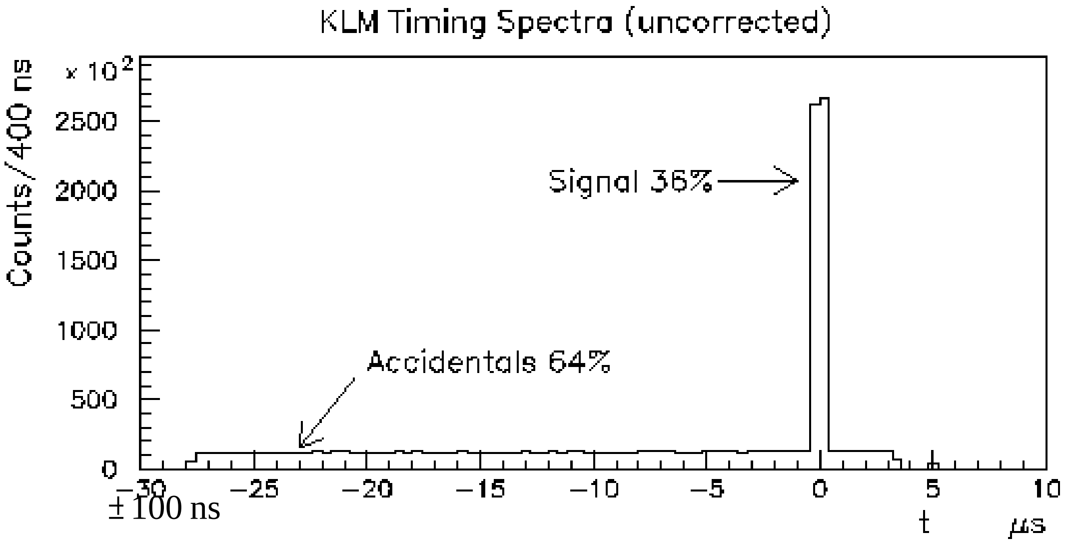
System Performance



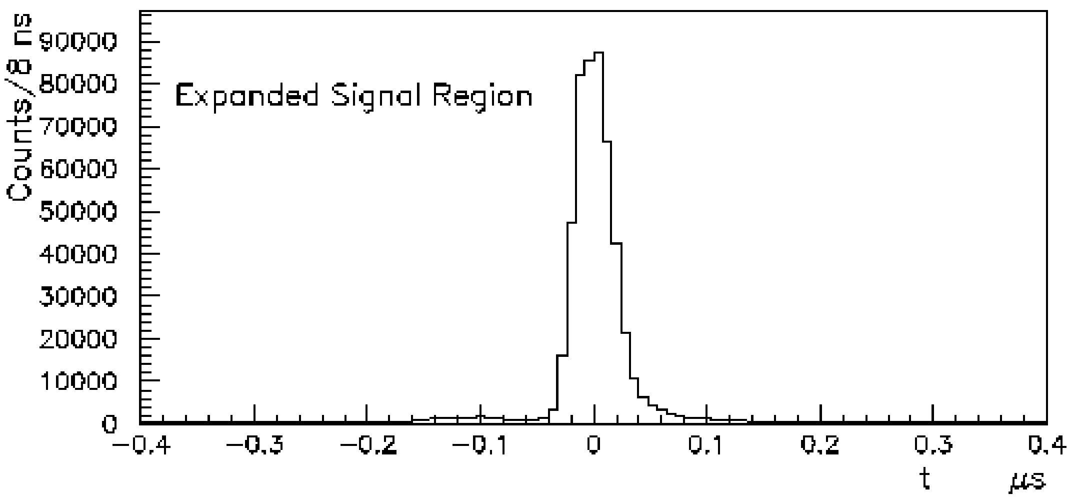
Cosmic ray plateau curves. The benefits of having redundant layers are evident.

Cosmic Ray Timing Spectra

The 32 us range of the TDCs pulls in a lot of noise hits, but most of the signal events are contained in a narrow (±100 ns) range around prompt.



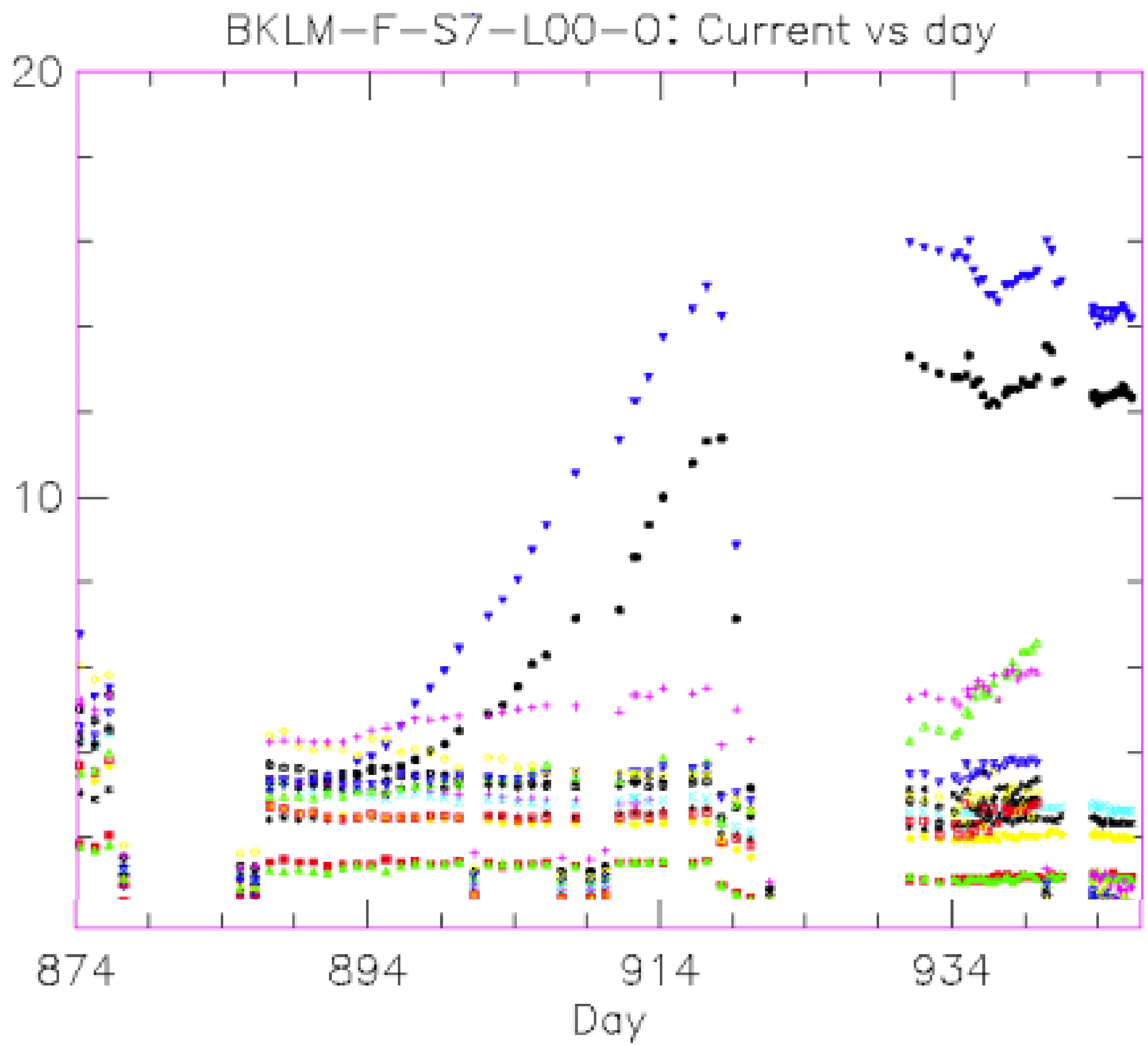
The timing errors are dominated by cable length variations (no corrections have been made).



A Major Problem Develops

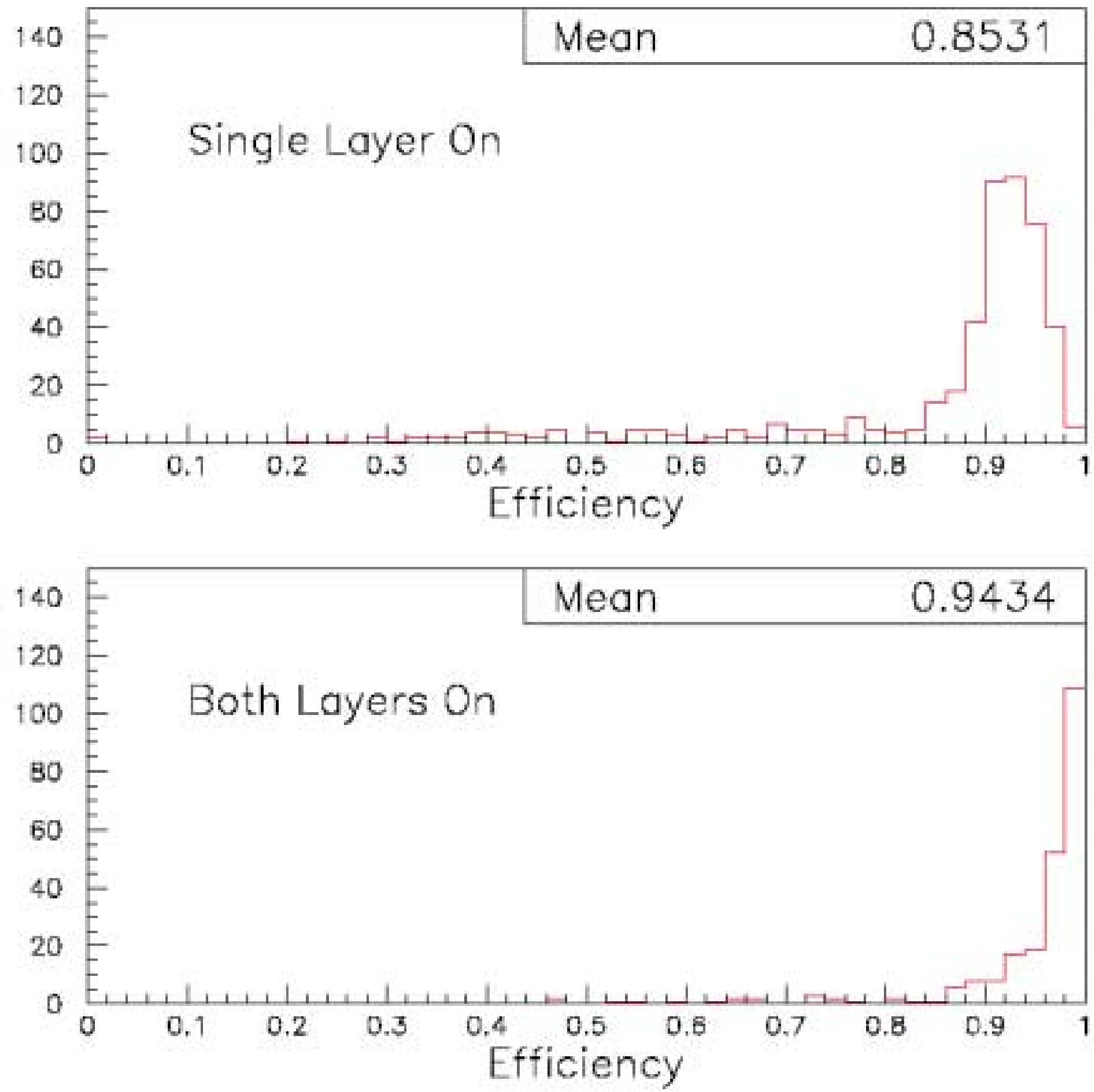
The first signs of trouble showed up shortly after installation and looked something like the plot to the right. The current from a chamber would "suddenly" show a dramatic increase.

Given that there is a "pedestal" current resulting from the spacers, the true dark-current increase was in fact substantial.



. . . A Major Problem Develops

Many RPCs showed a dramatic loss of efficiency. The situation became so bad that we decided to switch off the system (which turned out to be a lucky guess!).



. . . A Major Problem Develops

- The problem started to show up almost immediately upon installation in June of 1998.

- The number of high-current RPCs increased steadily over the summer. The failure rate increased dramatically in late August, forcing us to shut down the system pending a better understanding.

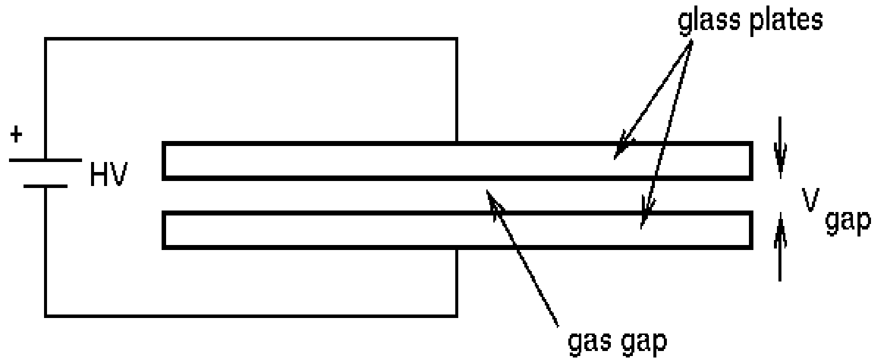
- High current is a serious problem in glass RPCs (see next slide).

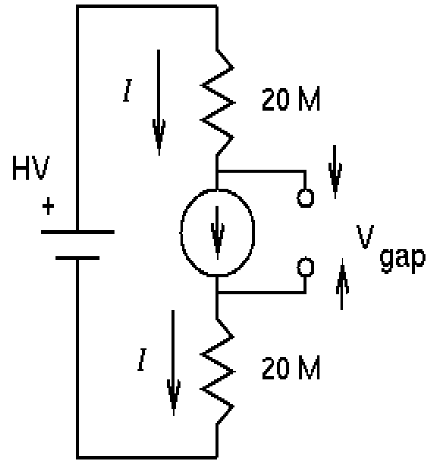
. . . A Major Problem Develops . . .

High dark currents induce a significant IR voltage drop across the glass plates, which lowers the voltage across the gap, causing the chamber to slide off the efficiency plateau.

Increasing the applied voltage doesn't help since it merely results in increased dark current.

The is what I like to call the classic "RPC Death Spiral".



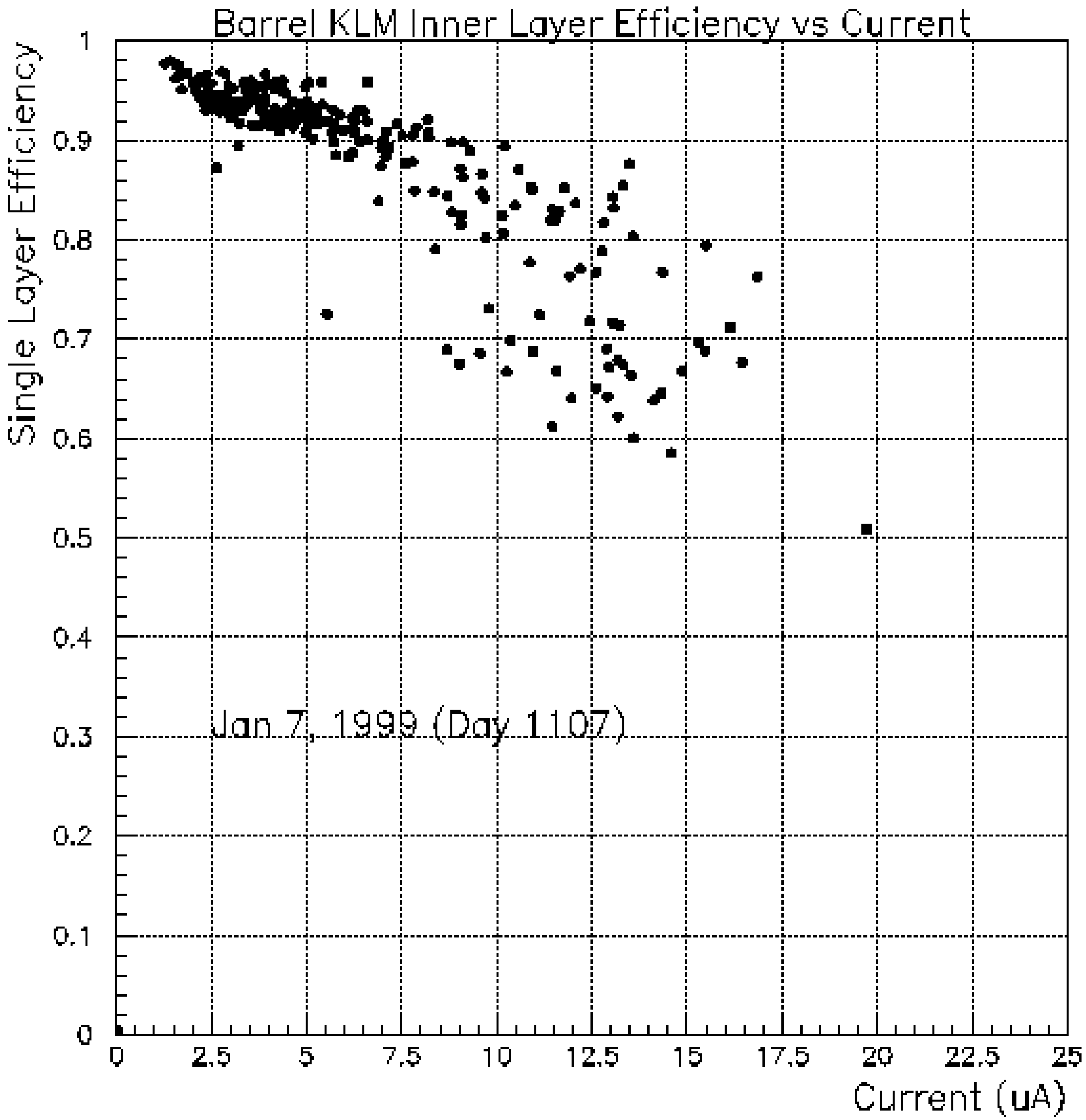


V_{gap} = HV − IR = HV −10 uA x 40 M

= HV −400V

A Major Problem Develops . . .

The expected correlation between dark current and efficiency loss is readily apparent.



A Solution Emerges . . .

- After several weeks of study we determined that the problem was due to high levels of water vapor in the gas.

- Although we were aware of this problem (even more severe problems occurred in the early days of our R&D when some of our collaborators used urethane gas tubing, which is highly permeable), we had incorrectly assumed that water would not permeate our polyethylene (Polyflow) tubing.

. . . A Solution Emerges

• In fact we were susceptible to water contamination for the following reasons:

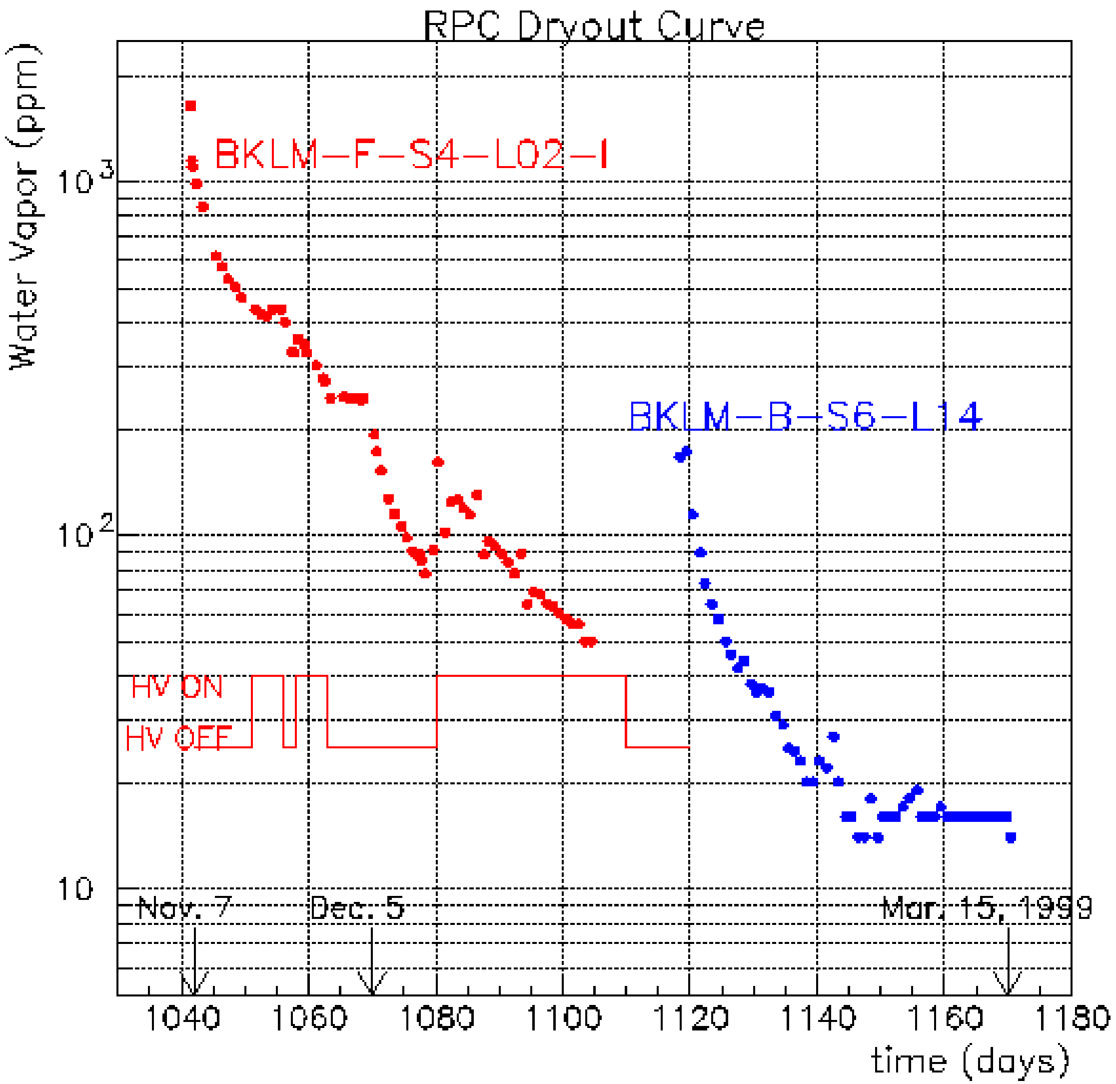
- Low flow rates
- Long (5~12 m) runs of plastic tubing.
- Hot and humid weather during the Japanese rainy season.

• Using published data for polyethylene, we were able to account for the ~2000 ppm concentrations of water vapor that we observed.

A Solution Emerges . . .

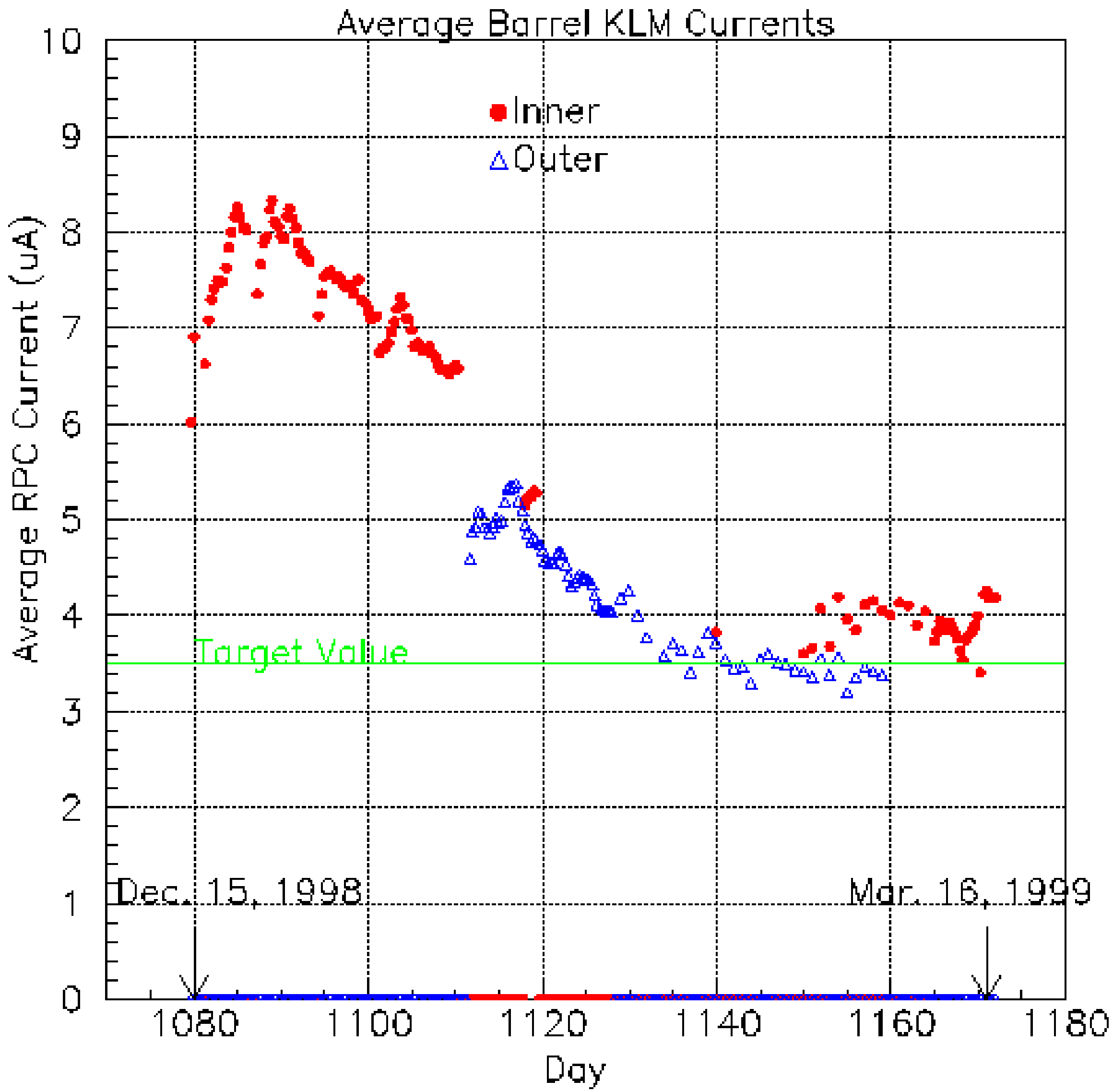
We replaced the long runs of polyethylene with copper (~5 km in all!) and flowed gas at the highest possible rate (~one volume change per shift).

Slowly, but surely, the RPCs began to dry out.

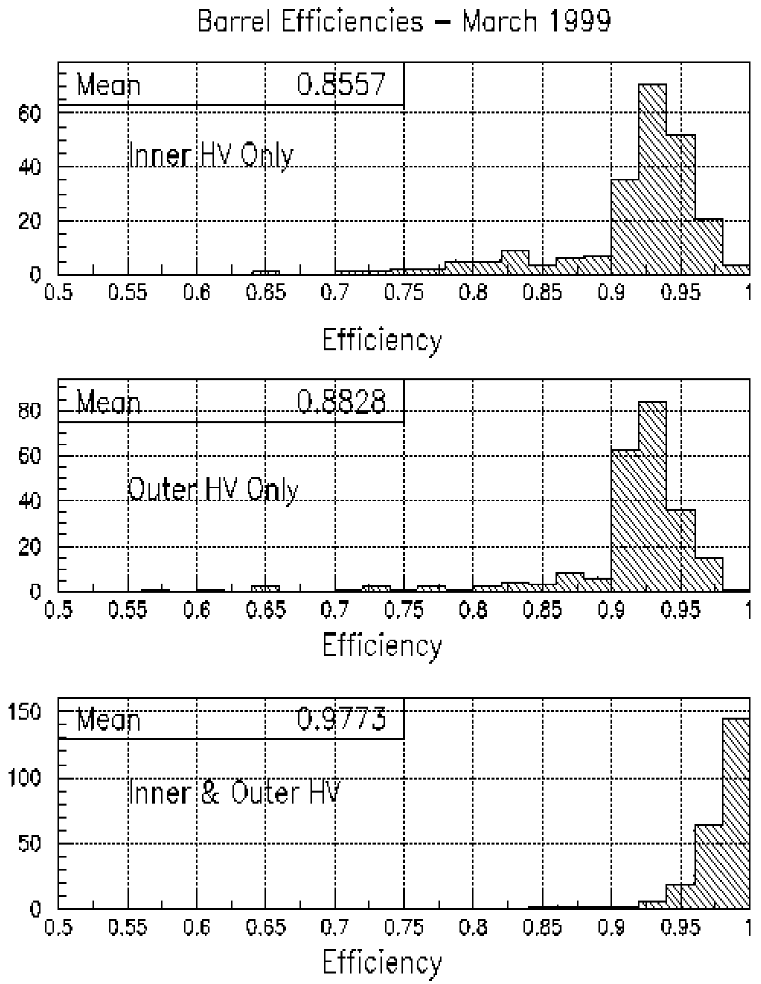


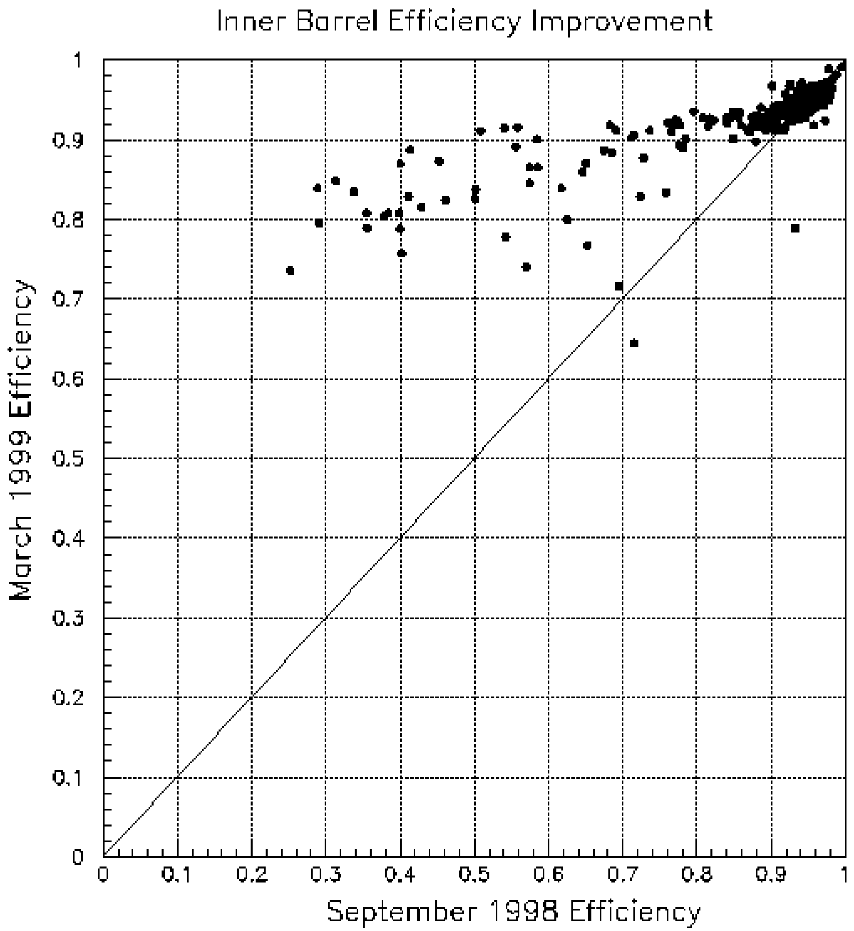
A Solution Emerges . . .

We were greatly relieved to see an accompanying drop in the dark currents!

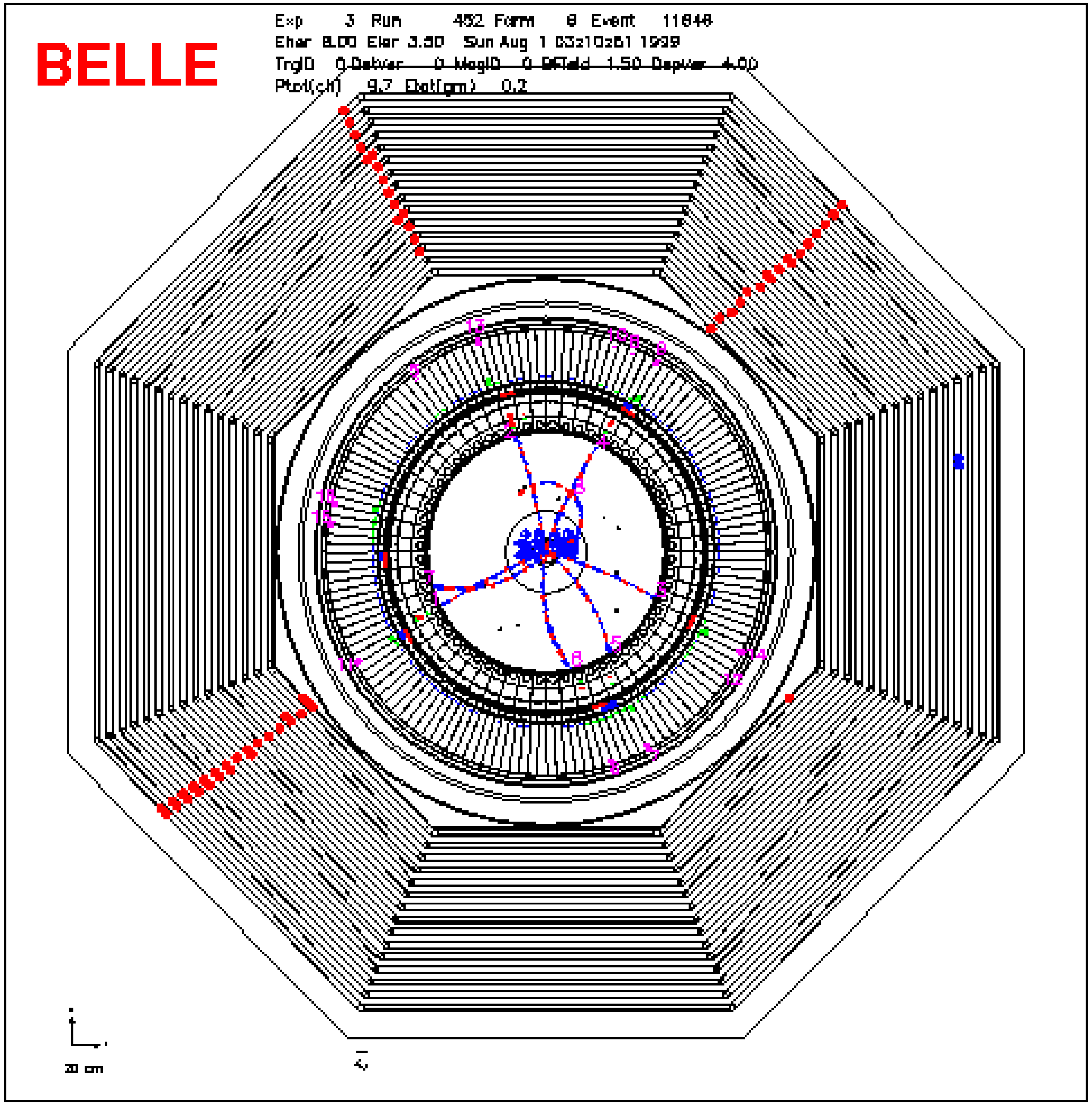


A Solution Emerges . . .





Although some residual damage remains, the situation is much improved.



$B^{+} - \ J/\Psi K^{+}$ candidate

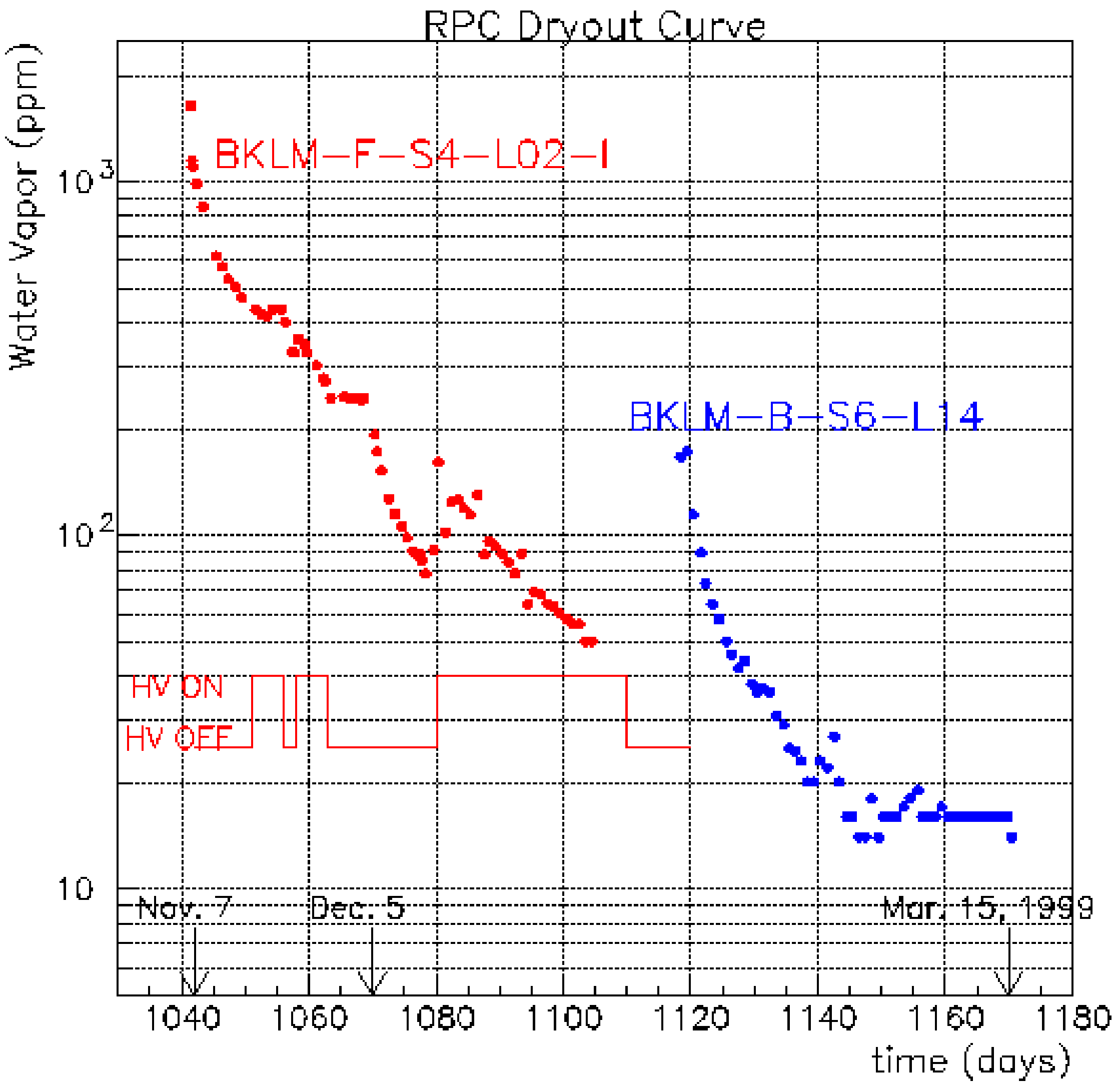
Efficiency

A simple test of system performance comes from looking for missing hits along muon tracks.

The three-muon event to the left shows that the RPC system is working well.

Where does all that water come from?

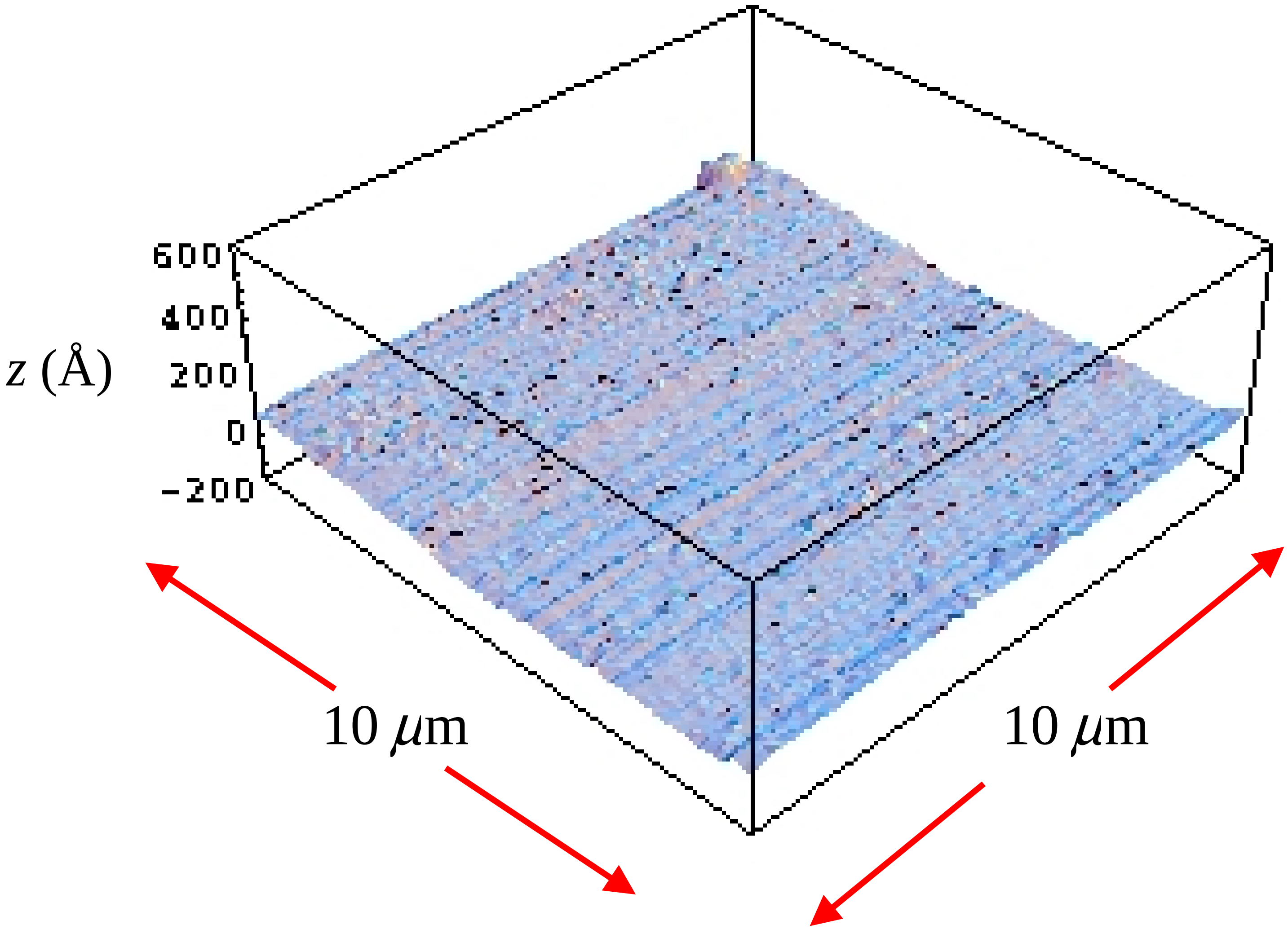
The RPCs continued to dry for over three months. All told an amount of water equivalent to ~100 monolayers was removed.



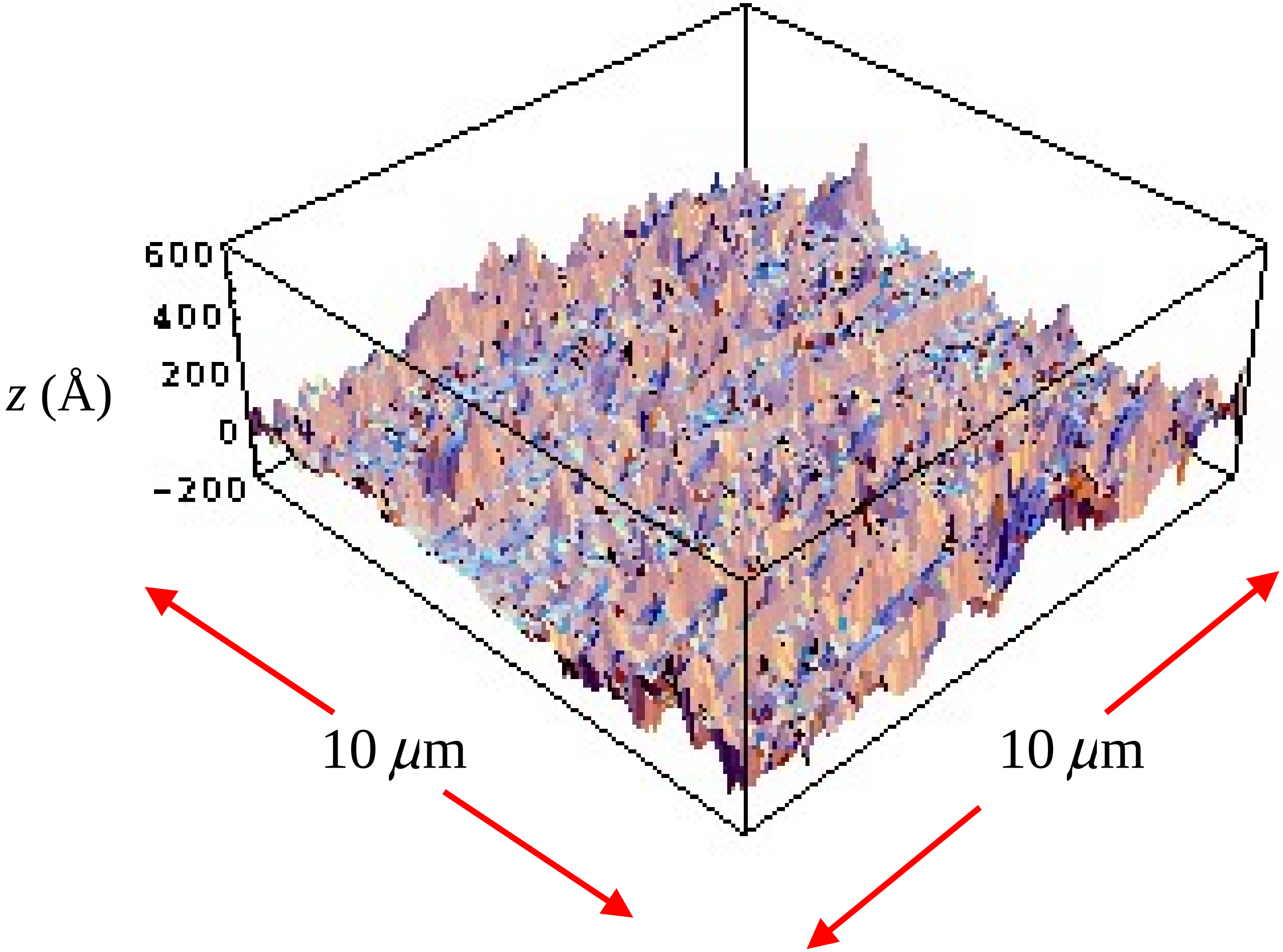
Where Does All That Water Come From?

- Naively one would believe that the surfaces could hold only ~three molecular monolayers.
- But that is true only for a smooth surface.
- As we will see, the surfaces of chambers quickly become any but smooth.

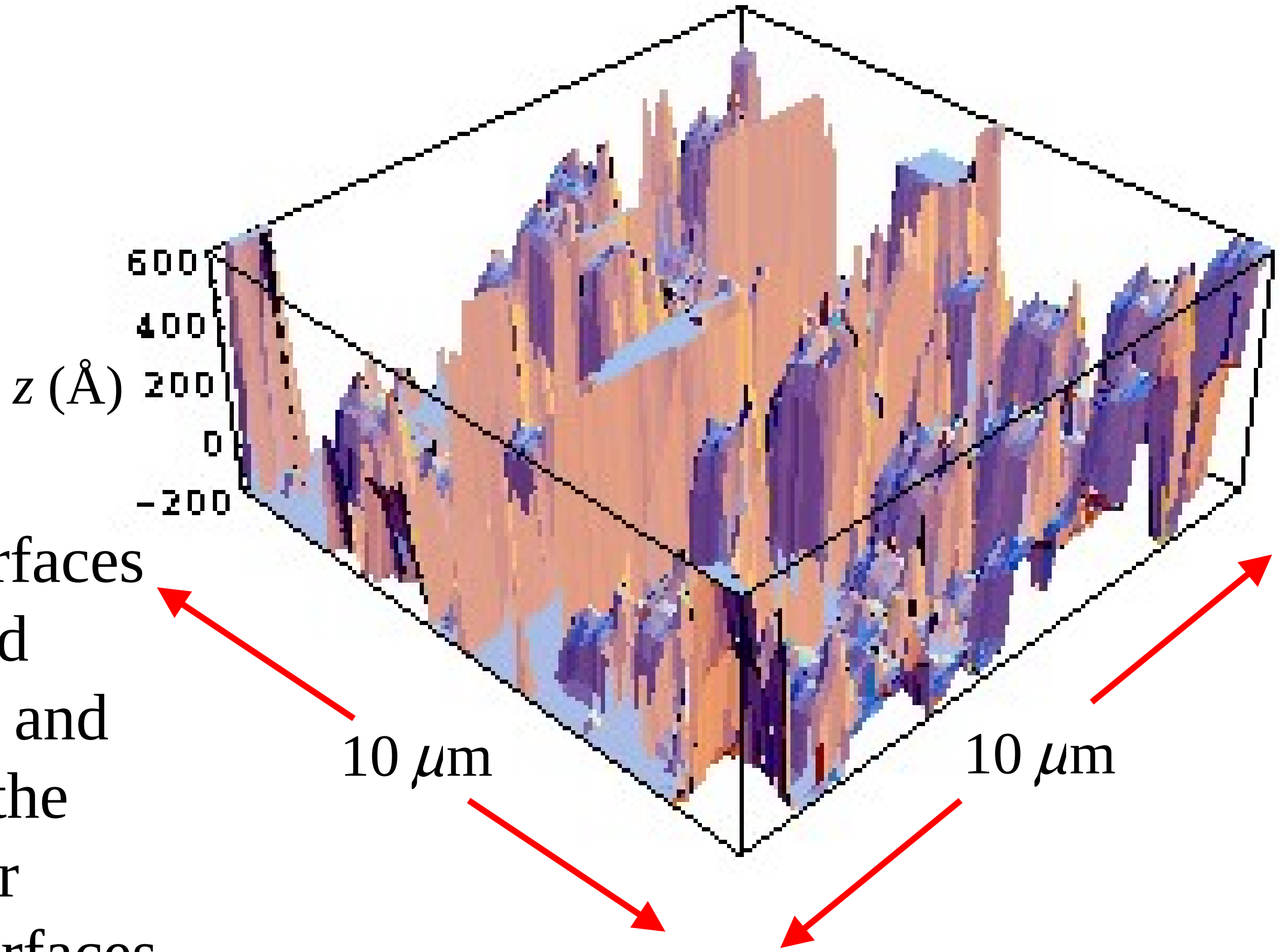
STM Picture of a Virgin Glass Surface



Surface of “Good’’ Anode



Surface of "Bad'' Anode

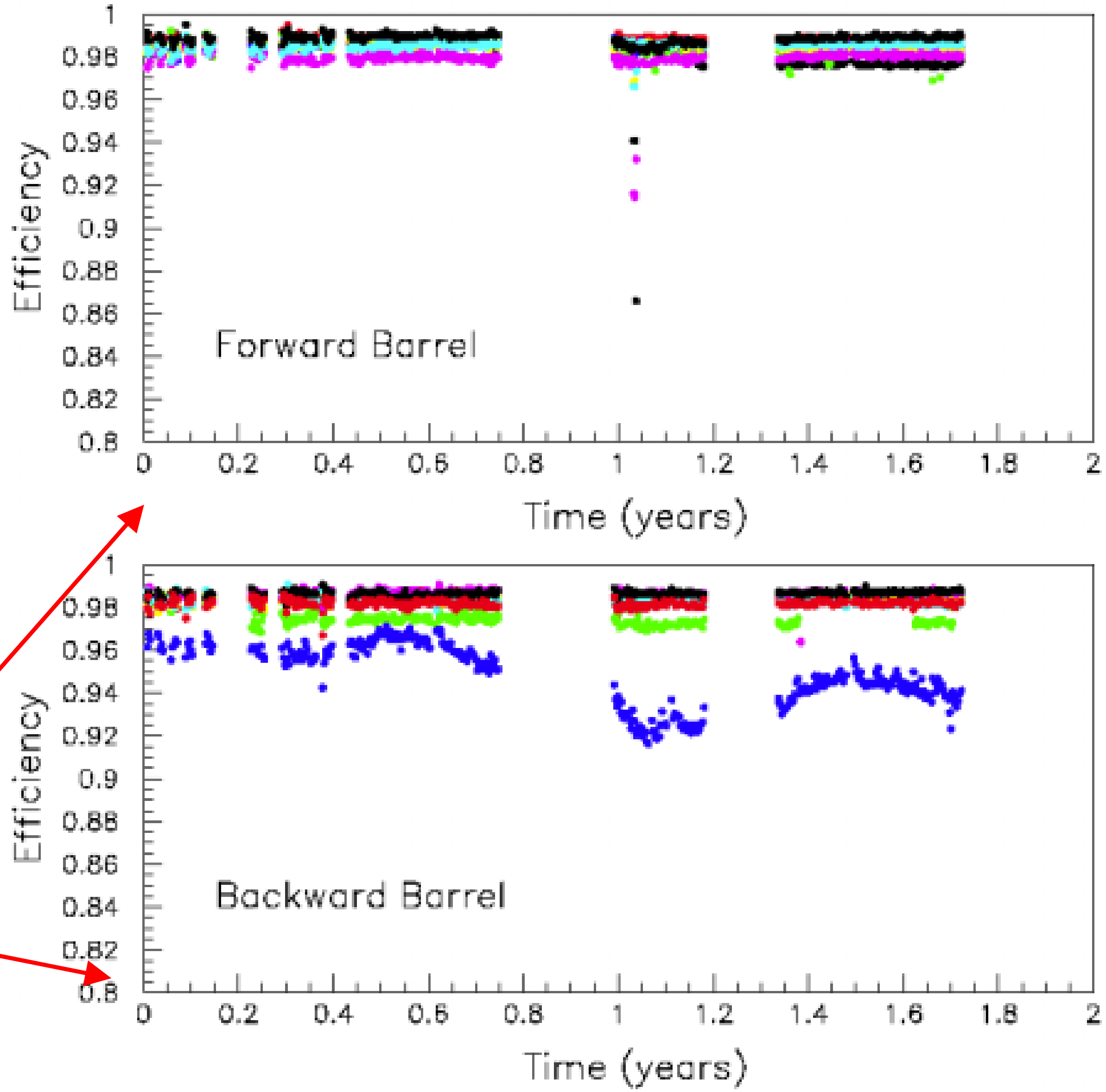


We believe that the surfaces were etched by HF acid formed from the water and the Freon (R134A) in the gas. The trapped water probably affects the surfaces conductivity of the glass.

Belle Efficiency History: Barrel

The barrel system has been stable since “dry out.” Small problems are masked by the redundant readout arrangement.

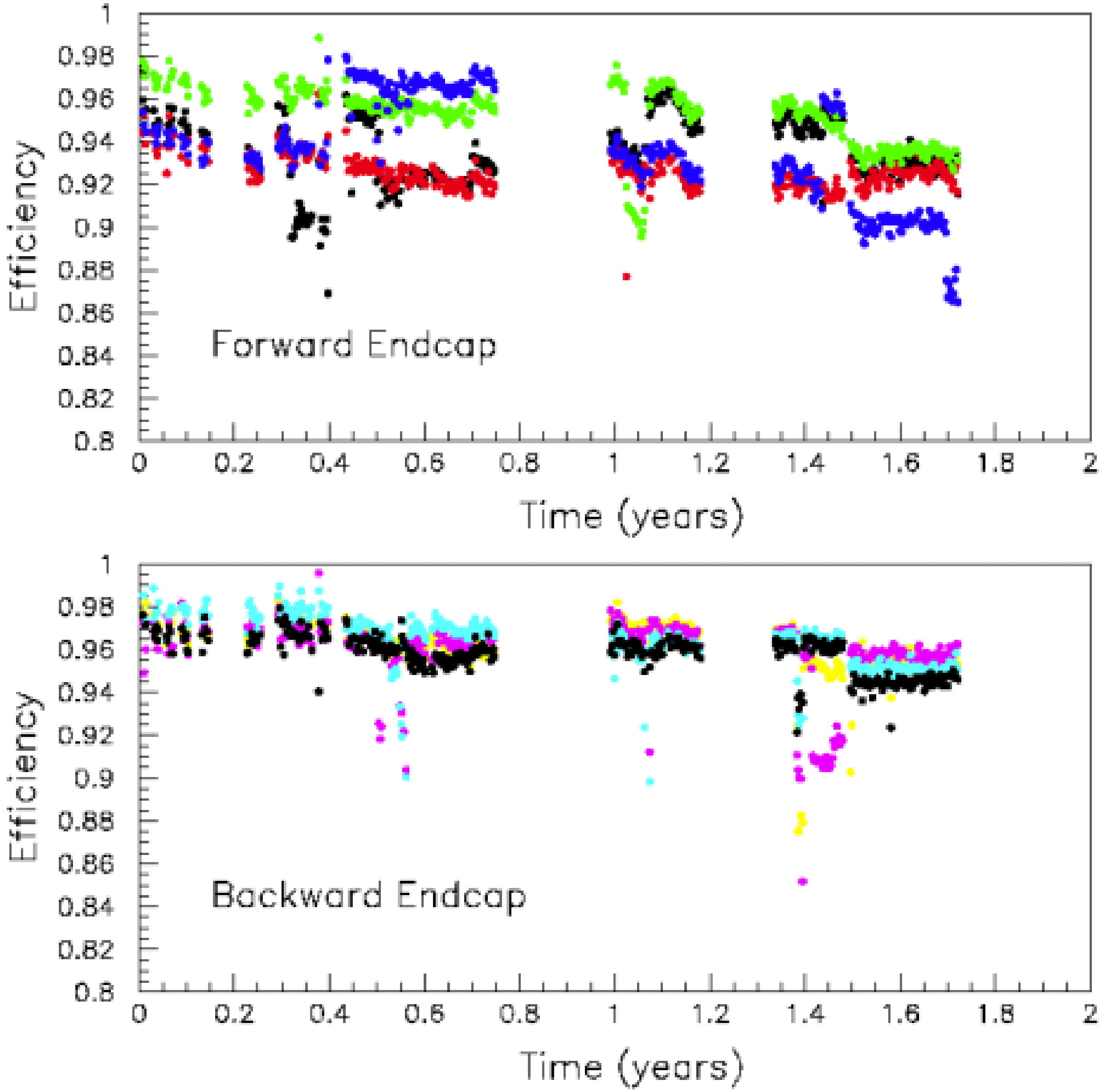
Oct. 1999



Note suppressed zero!

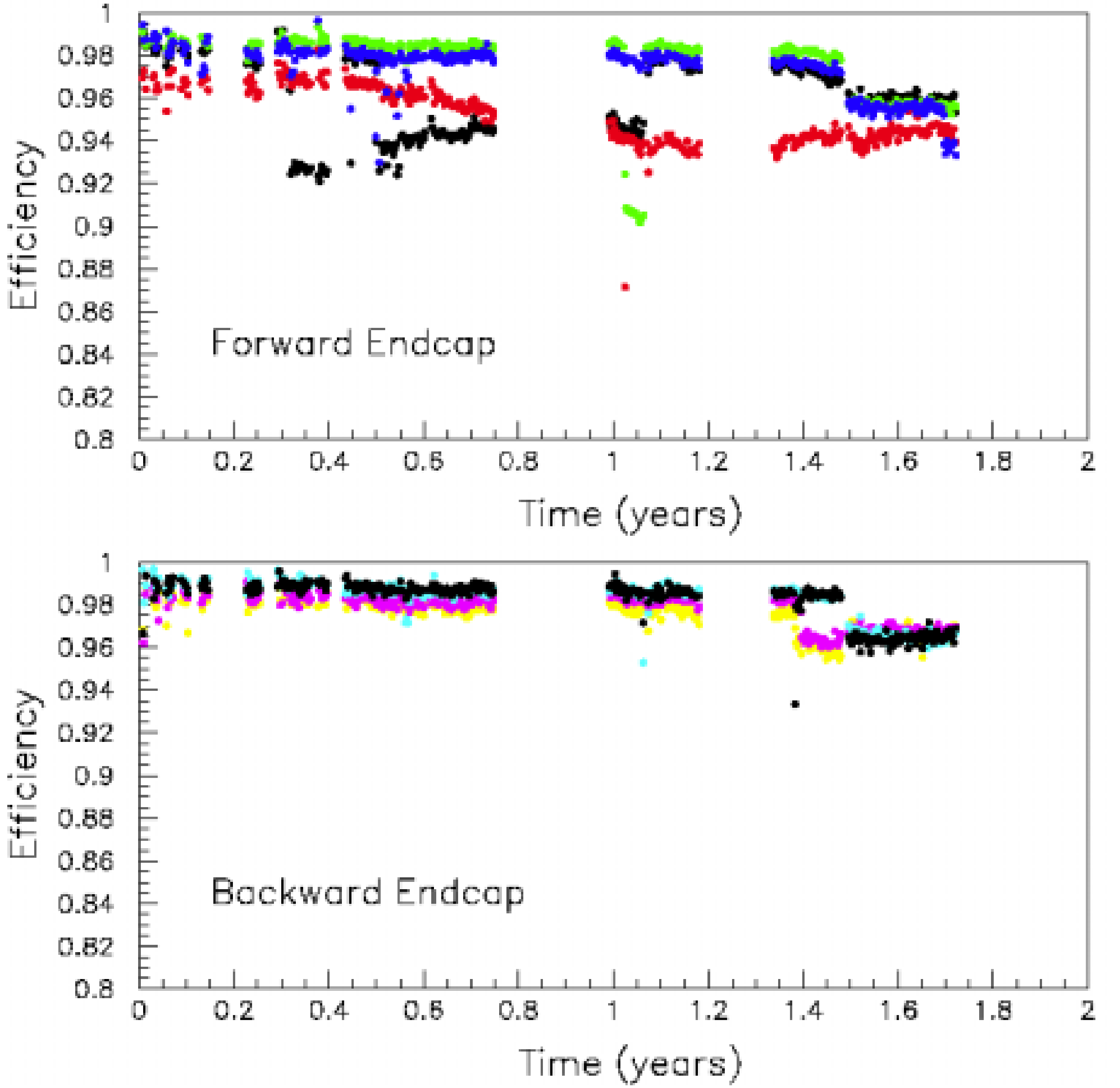
Belle Efficiency History: Endcap

The endcap system has seen some degradation over the past two years. This may be the result of high rates in the layers that are exposed to the beam.



Belle Efficiency History: Endcap

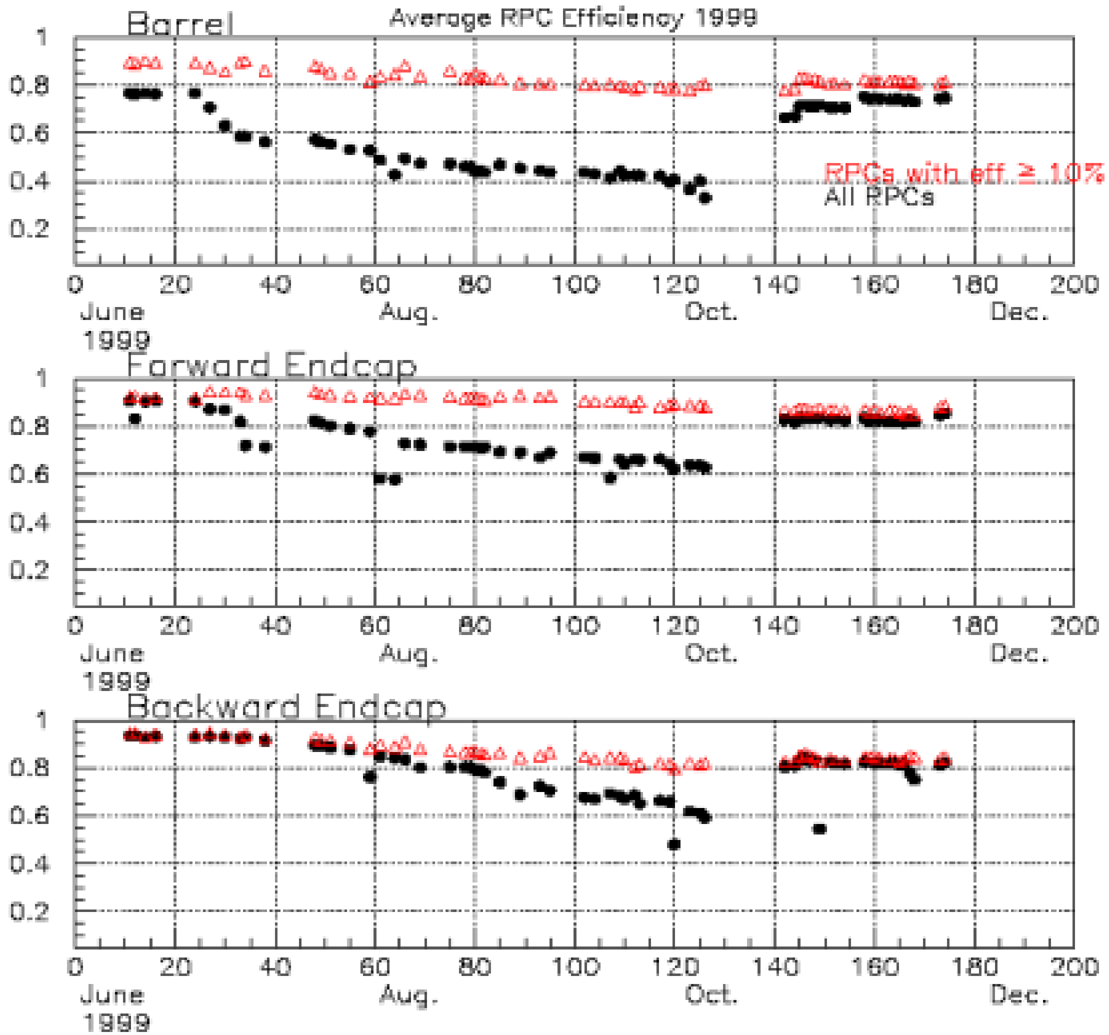
The situation improves when the outer layers, which are exposed to beam backgrounds are removed from the averages. The available data cannot unambiguously distinguish between aging and rate effects.



BaBar

The bakelite RPCs in BaBar have exhibited serious efficiency loss. Attempts at a lasting antidote have not yet been successful.

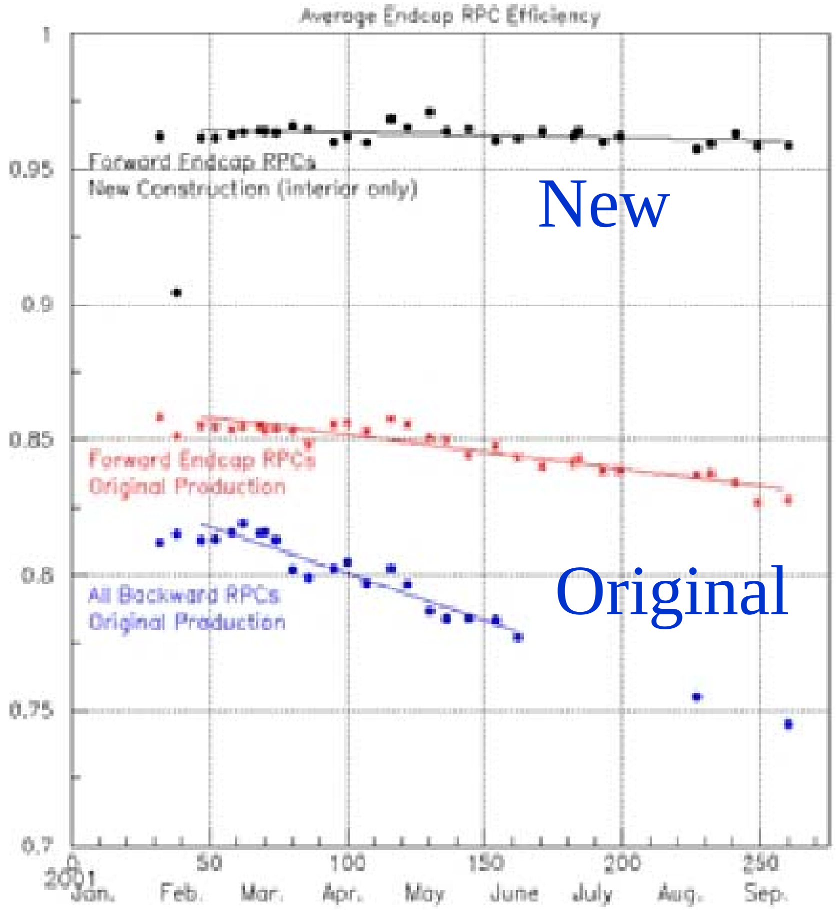
1999



BaBar

Newer RPCs seem to being faring better.

⇒The problems that afflicted BaBar also appear to be episodic (poor QC during construction and/or careless handling during early operation).



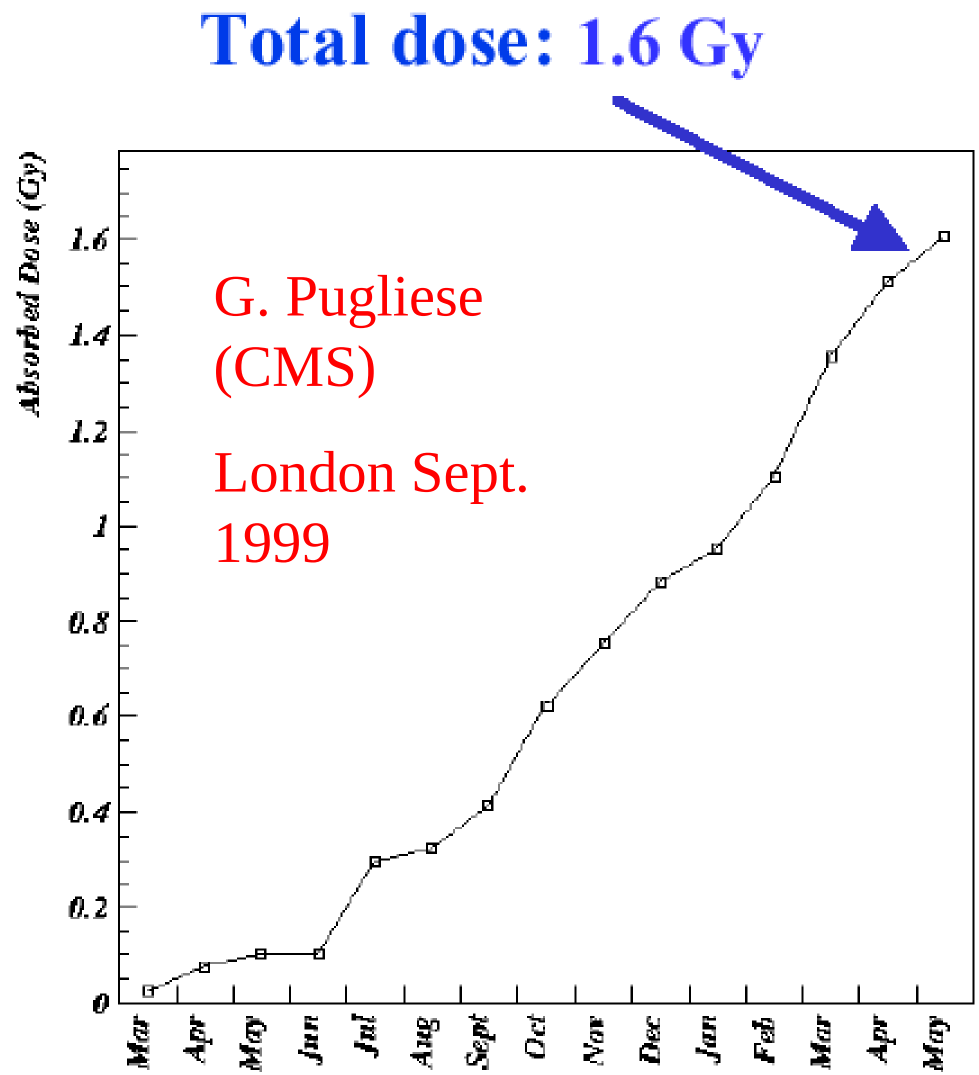
See talk by D. Piccollo.

What About Conventional Aging?

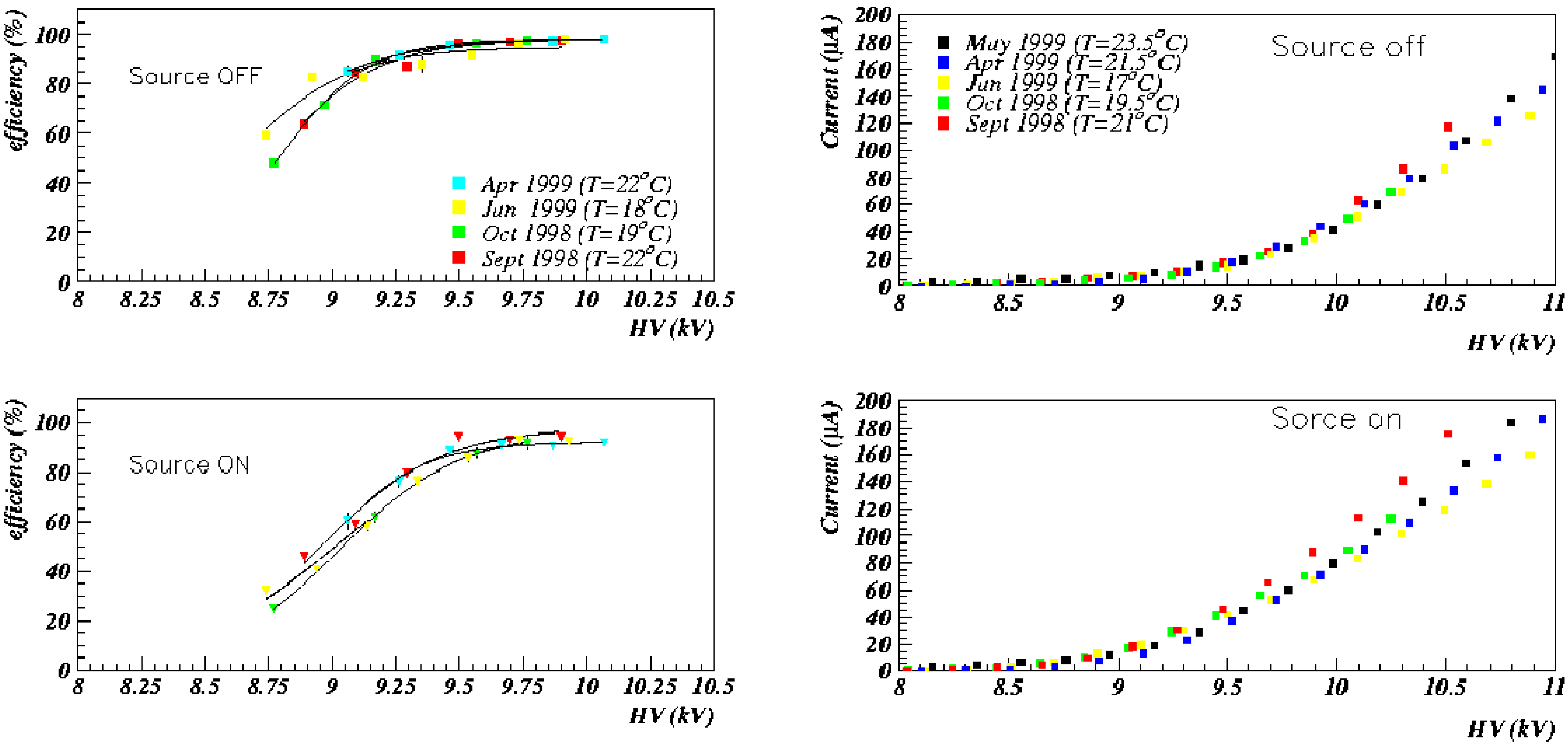
With the exception of some modules that see large beam backgrounds, the integrated doses at the B Factories are small.

That will *not* be the case at the LHC.

Here conventional aging studies are needed.



What About Conventional Aging?



G. Pugliese (CMS)

London Sept. 1999

Streamer mode, Q_{total}= 0.05 /cm^2/gap

Summary and Conclusions

- The two largest deployments of RPCs have *not* been unqualified successes:
    - The Belle RPCs came close to disaster, but seem to be OK now.
    - The BaBar RPCs have suffered serious damage that appears to be irreparable.
- The problems are not classic aging problems and probably would not have shown up in standard accelerated aging tests.

. . . Summary and Conclusions

• Data from LHC R&D aging tests indicate that under the right circumstances, RPCs can withstand large integrated doses.

• Many of the good things that were said about RPCs are true, but *there are no miracles*.

• Unpredictable surface effects make RPCs particularly finicky (c.f. CsI photocathodes, MSGCs).

. . . Summary and Conclusions

- As with most detector technologies it is important to:
  - maintain the high QC standards during manufacture.
  - treat RPCs as the delicate instruments that they are during operation.
- If this is done, RPCs will probably work OK, but if I had to do it over again I would take a long hard look at scintillating strips.